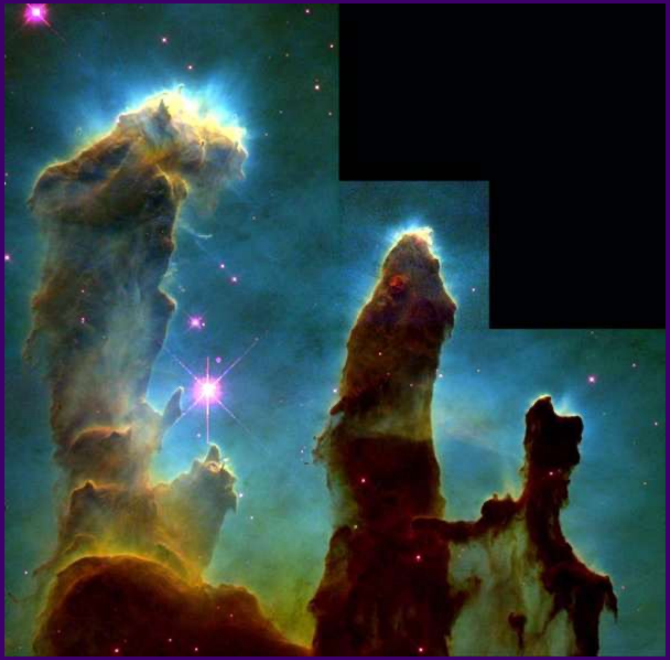


Our Solar System and Others

Today:

- Solar system patterns
- Age of the solar system (and a crash course in nuclear physics)
- Formation of the solar system
- Planets around other stars

Solar System Patterns

- The solar system is very flat. Why?
- Nearly all the planets orbit and spin in the same direction. Why?
- Inner planets are small; outer planets are big. Why?
- Inner planets are mostly solid; outer planets are mostly gas and liquid. Why?
- Inner planets have little hydrogen and helium; outer planets have lots. Why?

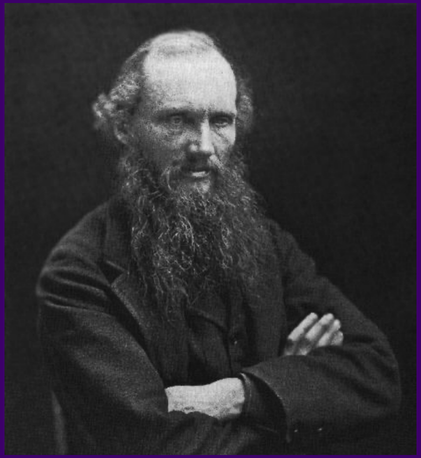
- Partial answers are not hard to guess…
- Detailed answers require an account of how the solar system formed.

How old is the solar system?

Age of the earth?

- Layered rocks imply an age of *at least* millions of years.

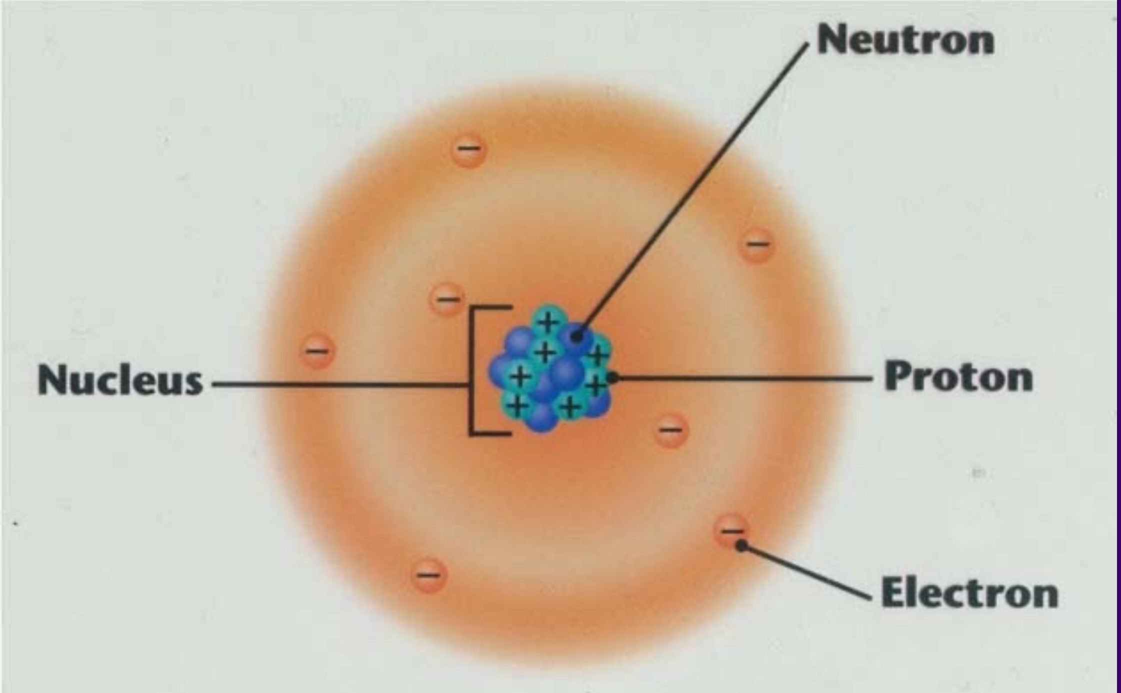
- Earth’s hot interior implies an upper limit on its age (as does sun’s energy output).



William Thomson, Lord Kelvin

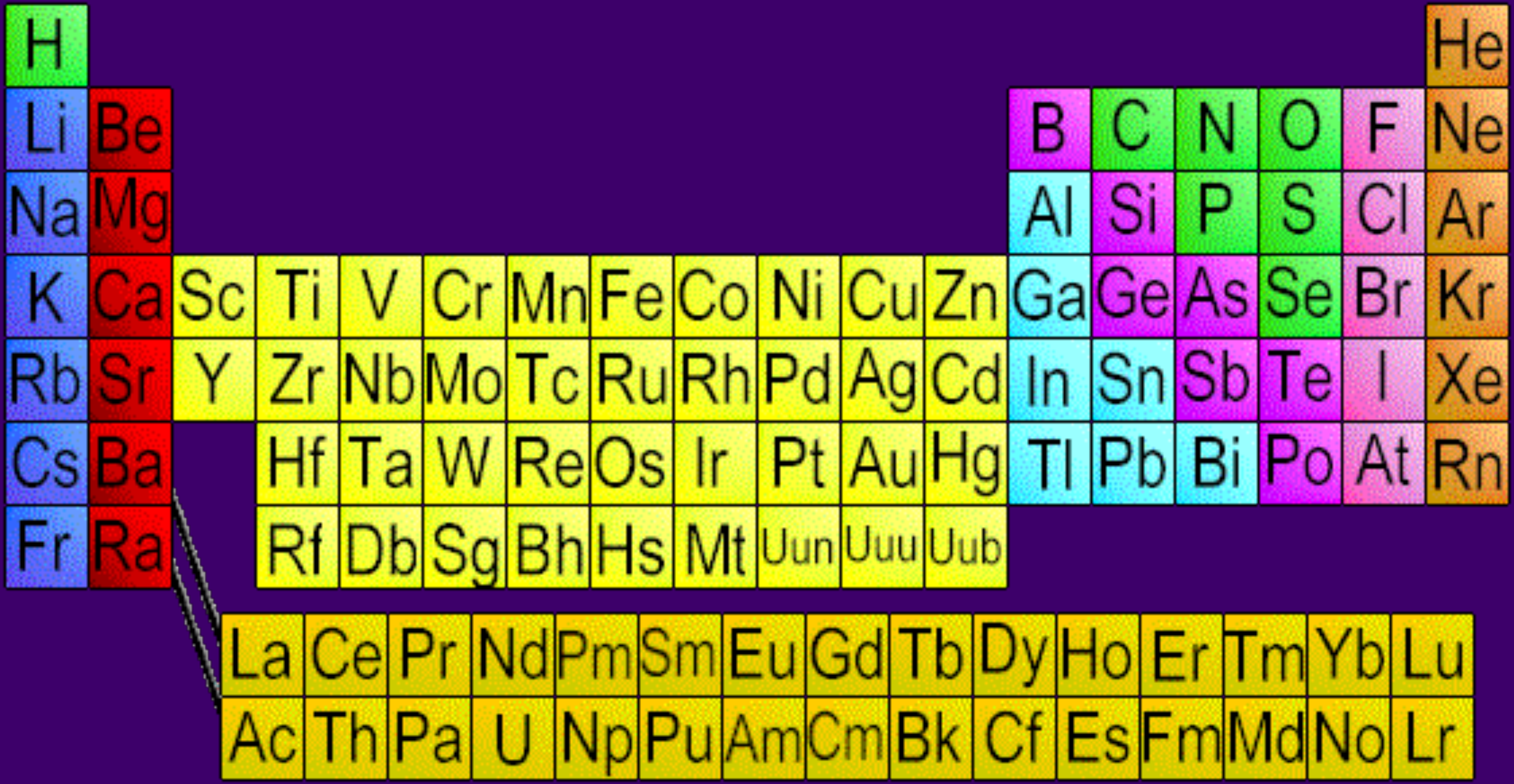
How old is the solar system?

To get an actual number, we need nuclear physics.



Each chemical element has a different number of electrons (and an equal number of protons).

The Periodic Table

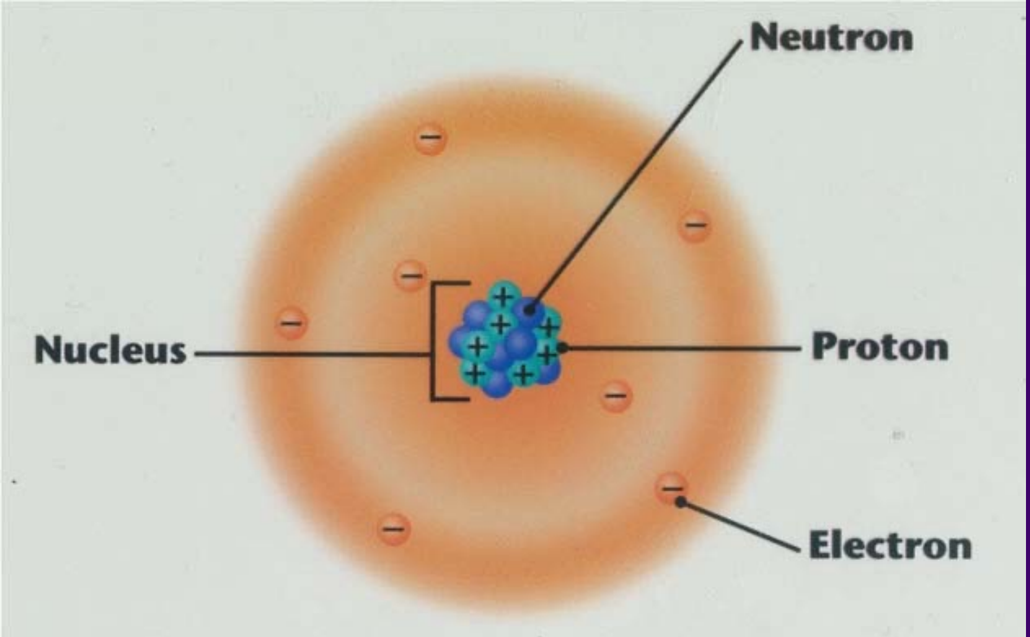


H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Masses and rarities increase (mostly) toward the bottom of the table.

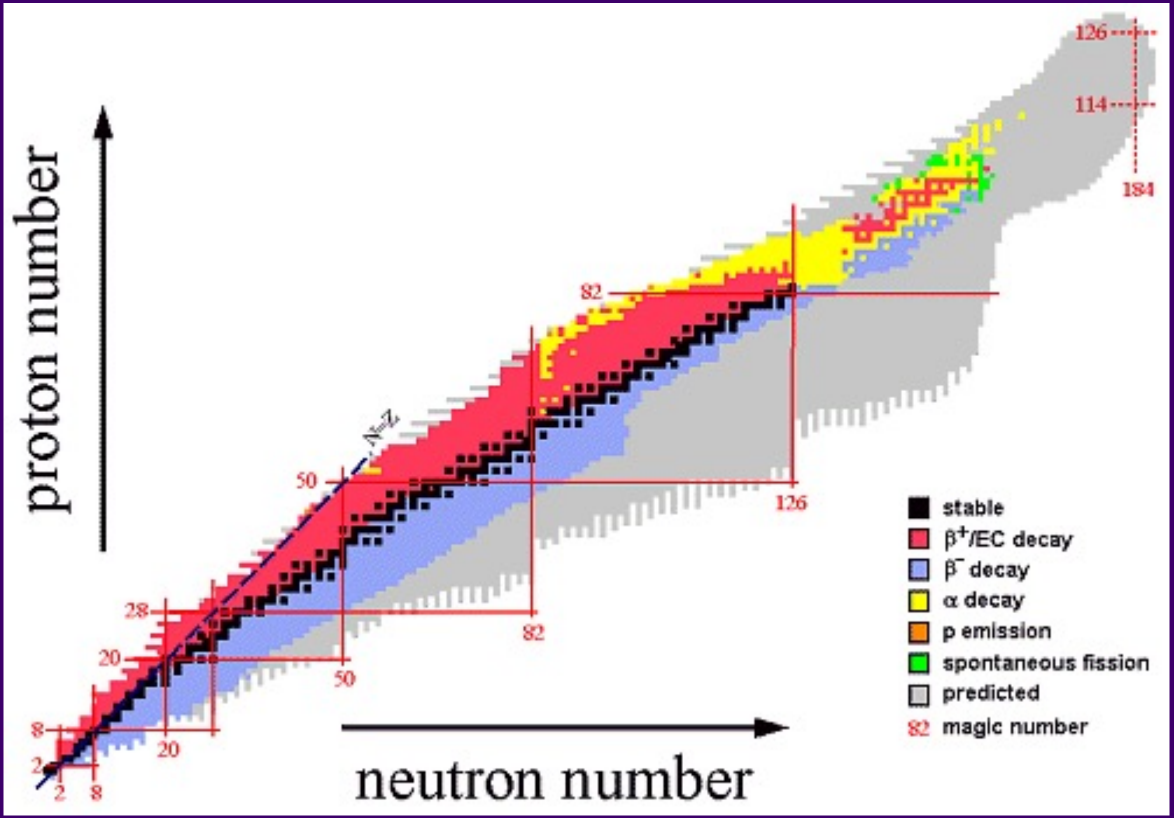
Nuclear Isotopes

Same element, different numbers of neutrons (hence different masses).



Examples: Hydrogen-1 (1p, 0n); Hydrogen-2 (1p, 1n); Uranium-235 (92p, 143n); Uranium-238 (92p, 146n).

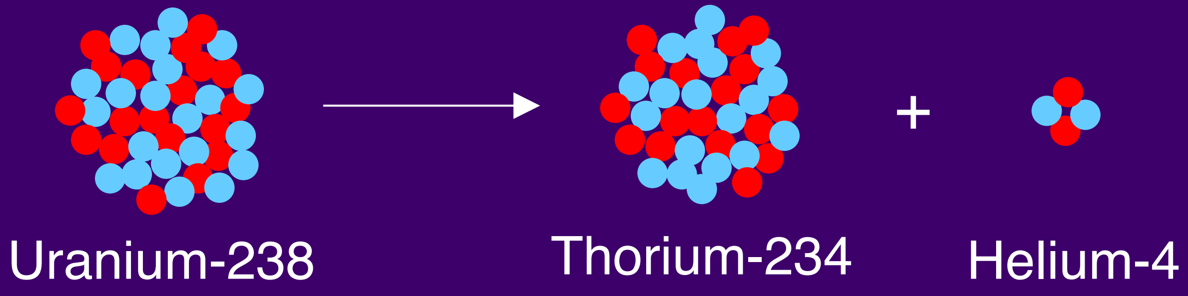
Nuclear Isotopes



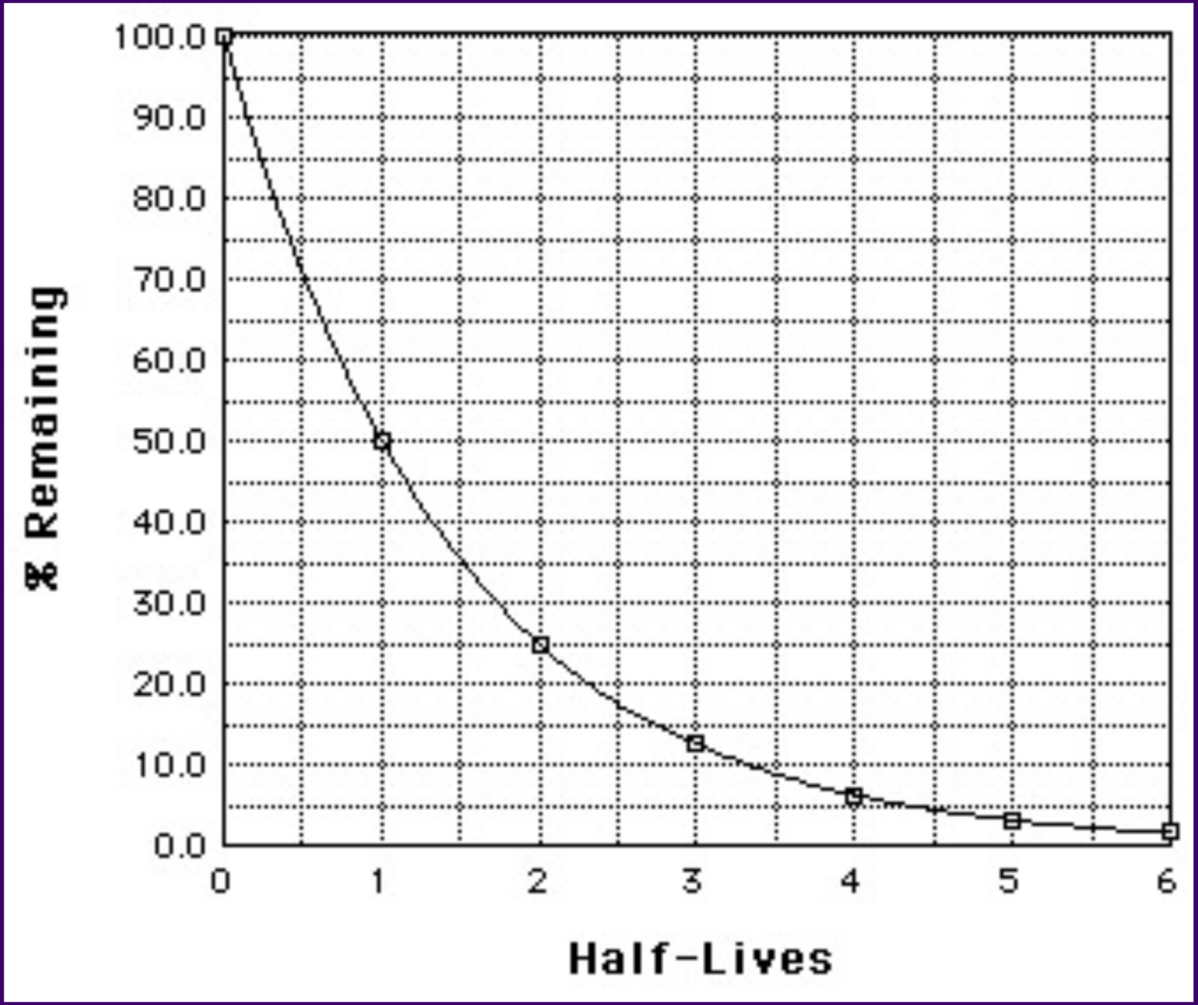
Of all the thousands of possible isotopes, only a few hundred are stable. These tend to have slightly more neutrons than protons. Others spontaneously decay.

Nuclear Decay (“Radioactivity”)

- Unstable nuclei spontaneously disintegrate, usually by emitting a helium-4 nucleus (2p+2n) or an electron (converting a neutron into a proton).
- The time when any particular nucleus will decay is random and cannot be predicted.
- Rather, each isotope has its own “half-life,” the time in which a nucleus has a 50% chance of decaying.
- Half-lives range from less than a millisecond (highly unstable isotopes) to billions of years (nearly stable).



Nuclear decay of a large sample



Radioactive Age Dating

Example: Potassium-40 decays to Argon-40 with a half-life of 1.4 billion years.

- A small percentage of all natural potassium is the radioactive isotope, potassium-40.
- As a rock ages, its potassium-40 slowly disintegrates, leaving argon-40 atoms behind.
- Argon is never incorporated into igneous crystals as they form, because it is a noble gas.
- Therefore the ratio of argon-40 to potassium-40 is a direct measure of a rock's age.
- Possible problem: Heating a rock can allow trapped argon atoms to escape. If a rock has been heated, it might be older than we think it is.

Radioactive Age Dates

- Farmington Canyon Complex:
  1.8 billion years
- Oldest earth rocks:
  about 4 billion years
- Oldest moon rocks:
  4.6 billion years
- Most meteorites:
  4.6 billion years

Another interesting pattern . . .

- Uranium 238 (half-life 4.5 billion years) is 140 times more common than uranium-235 (half-life 0.7 billion years). Other isotopes of uranium are not found on earth, although some have half-lives in the millions of years.
- Elements heavier than uranium do not occur naturally at all on earth. The longest-lived example is an isotope of plutonium with a half-life of 80 million years.
- Of the hundreds of isotopes with half-lives under 100 million years, only a few are found naturally on earth. These are being formed continuously by decay of heavier isotopes or cosmic ray bombardment.
- Explanation: The earth is made of stuff that's billions of years old, so short-lived isotopes are long gone.

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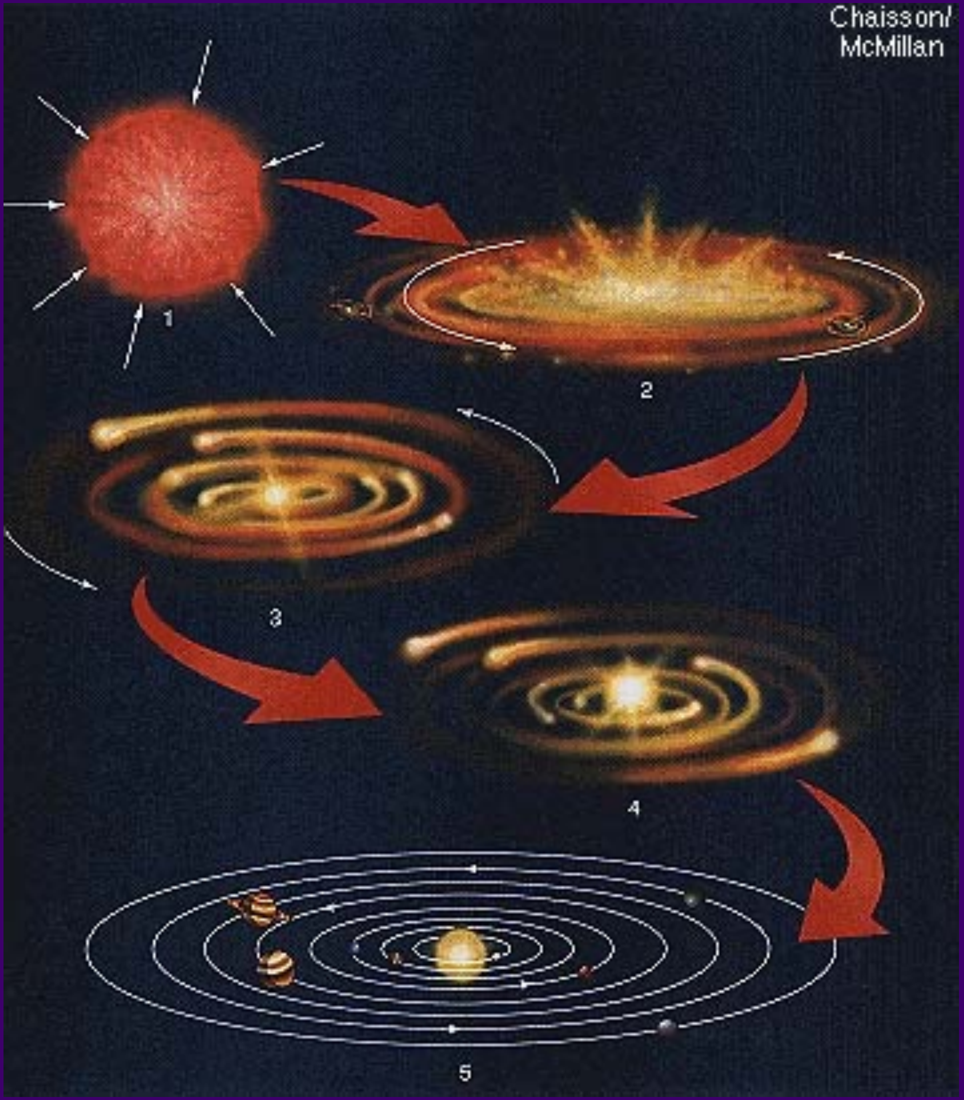
- Partial answers are not hard to guess…
- Detailed answers require an account of how the solar system formed.

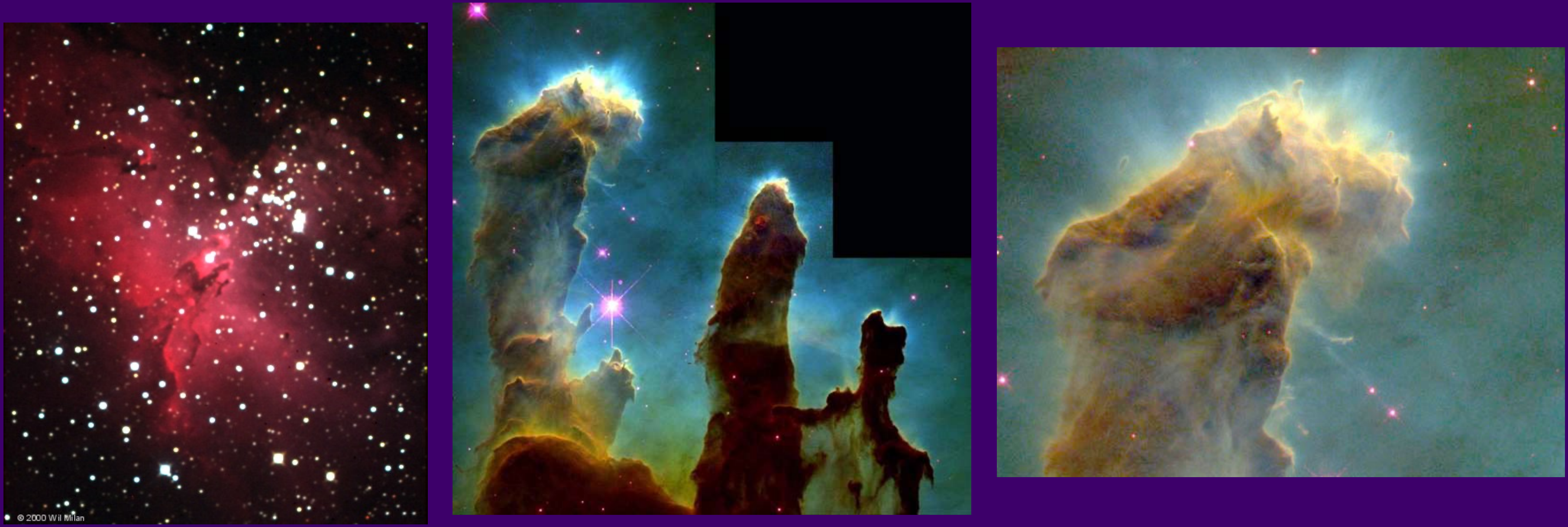
Formation of the Solar System

- Gravitational collapse of a cloud of gas and dust
- Centrifugal effect gathers material into a disk
- Particles collide and clump together, eventually forming planets, etc.



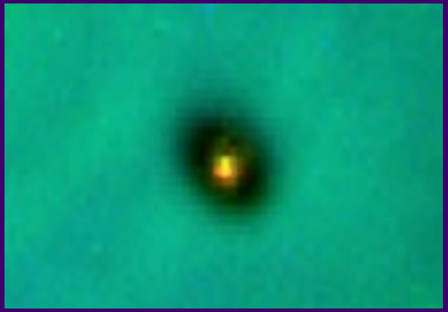
How can we test this theory?

1. Computer simulations
2. Look for other examples!



“Eagle Nebula”

Star formation in the Orion Nebula



Formation of the Solar System

(Details)

- Near the sun, it was too hot for light atoms and molecules to condense into solid clumps.
- The sun continuously emits high-energy particles ("solar wind") that can push light atoms out of the inner solar system.
- At Jupiter and beyond, it was cold enough for light atoms to condense (and the solar wind was weaker).

Solar System Patterns

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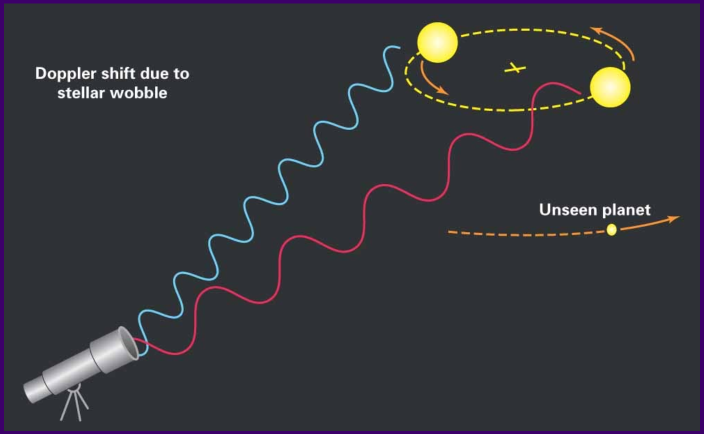
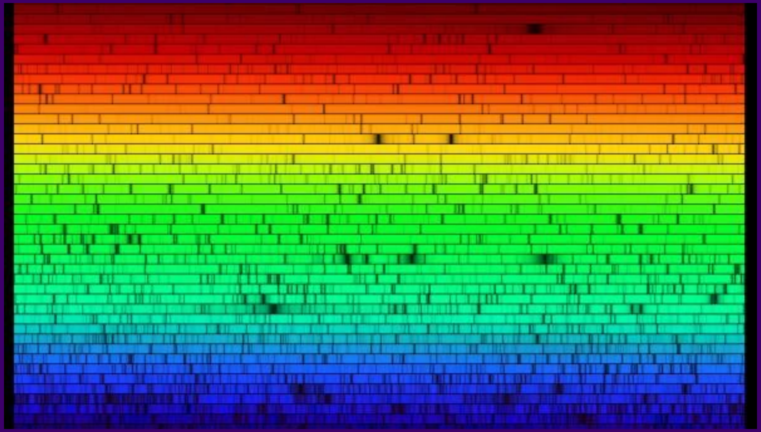
- Inner planets have little hydrogen and helium; outer planets have lots.

- Our theory seems to explain it all, but more testing is still required!

Further test: Look for other solar systems

- *Not easy*: Other stars are so far away that planets are invisible
- Best current method: Look for Doppler shift in a star's spectral lines, indicating wobble due to the gravitational pull of an orbiting planet.





- Another method: Look for periodic dimming of a star, caused by an orbiting planet passing in front.

Success!

>5000 extrasolar planets discovered in last 25 years

- Nearly all are massive: comparable to Jupiter

- Most are much *closer* to their stars than Jupiter. How is this possible? Our theory predicts that giant planets should be farther out!

- But our detection method is inherently biased toward these cases, since they produce the greatest stellar wobble.

Extrasolar planets